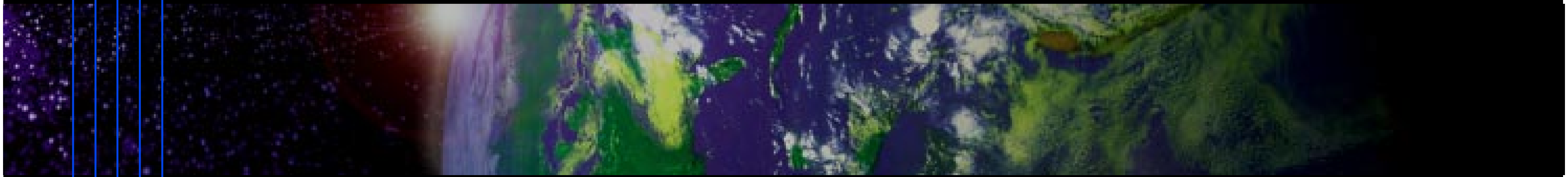
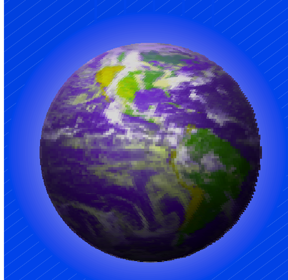


Earth Science Vision Introduction

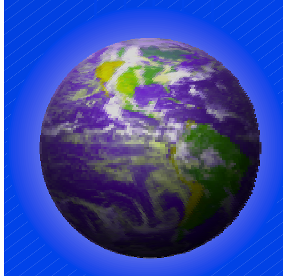
Dr. Michael G. Ryschkewitsch

January 27, 1999



Imagine if…

- We understand the causes and impacts of climate variability
- We routinely make global observations and have a comprehensive understanding of the global water cycle
  - We know the location and state of all fresh water resources on Earth
  - We understand and know the state of the biological, atmospheric and hydrological systems that make up Earth’s environment
  - We can accurately predict temperature and precipitation variations over seasonal time scales for any place on the Earth
  - We can put this knowledge in the hands of every practitioner and policymaker



…we can mitigate the impact of weather and climate on food production and fresh water resources

Revolutionizing Earth Science

- *We will create the ability to view the Earth as a complete and integrated system by*
  - *Enabling "discovery" of new events and interactions with new, real and virtual perspectives*
  - *Responding quickly and cost effectively to events in the Earth system and as our understanding grows with an intelligent sensorweb*
  - *Fully integrating observations, modeling, scientific analysis, and the practical applications from knowledge gained*
  - *Distributing information and knowledge to all users in a timely manner*

Radically Improve the Benefits to the Nation and Humankind

- Predict short-term climate change and use that information to enable strategic agricultural, mariculture and other resource management

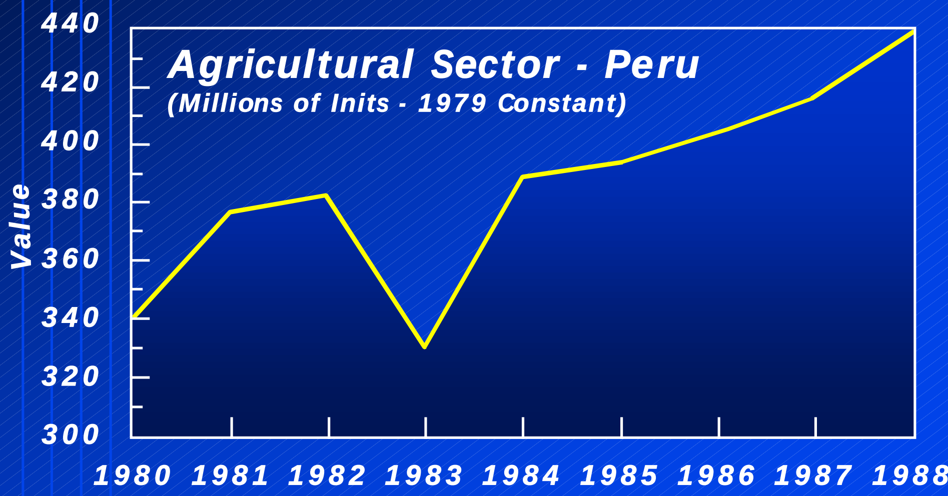
- Improve weather predictions and our knowledge of local systems to enable precision farming and cost sensitive operations

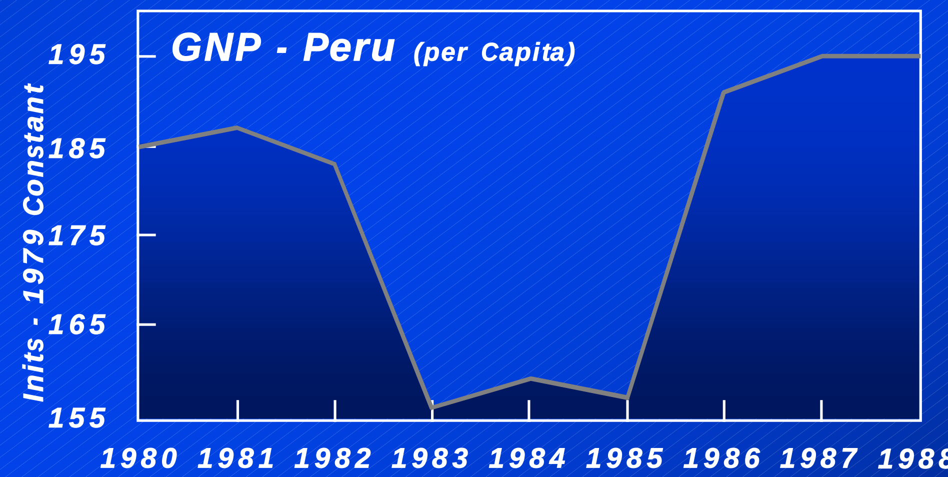
- Detect, interactively forecast and nowcast severe storms and use that information to save hundreds of lives and billions of dollars

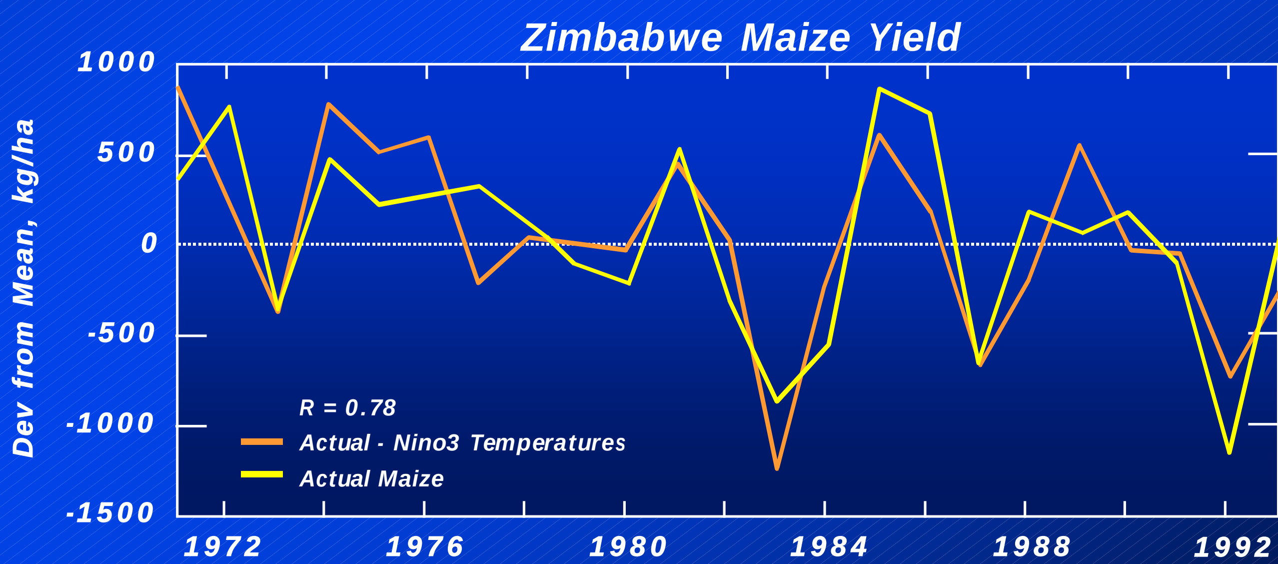
Example of Potential Benefits to U.S. Economy (annual)

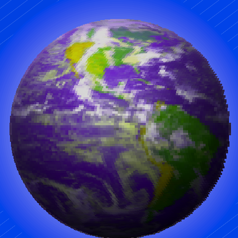
Economic Area	Gross Value	Potential Savings	Enabling Capabilities
Agriculture, fishing and forestry	$100 B	$10 B	• Accurate seasonal rainfall and temperature forecasts (e.g. enable strategic crop selection, planting, harvest time, etc.) • Accurate midterm temperature and rainfall forecasts to enable precision farm and crop management
Severe weather related loss	1500 lives/ $16 B	75 lives/ $0.8 B	• Precision storm track forecasts to allow highly targeted evacuations • Real-time storm tracking and localized forecast update for personal decision making and response - Nowcasting, Wristwatch weather
Airline fuel	>$25 B	$0.5 B	• Precision, global, frequently updated wind maps • Direct product distribution to aircraft

Effects of El Niño on Agriculture and GNP

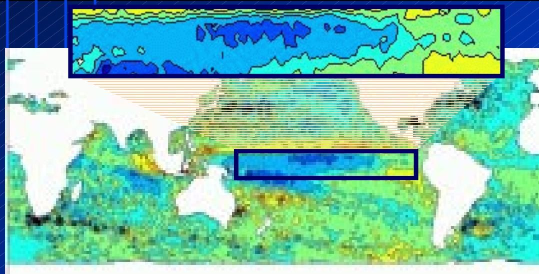






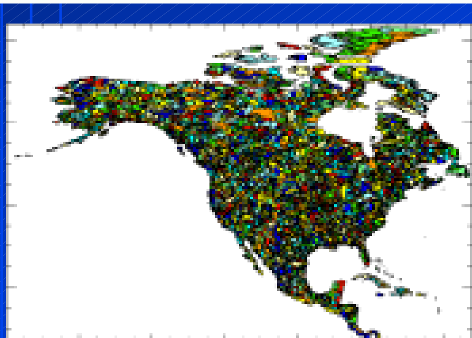


What Does This Mean in the Context of an ENSO-like Event?



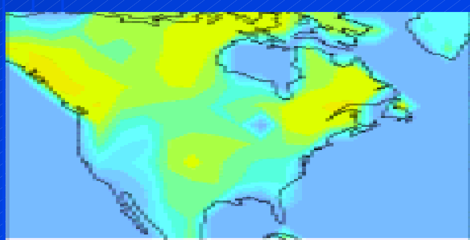
Sub-surface data needs

> 10^5 In-Situs
- Salinity, Subsurface Temperatures



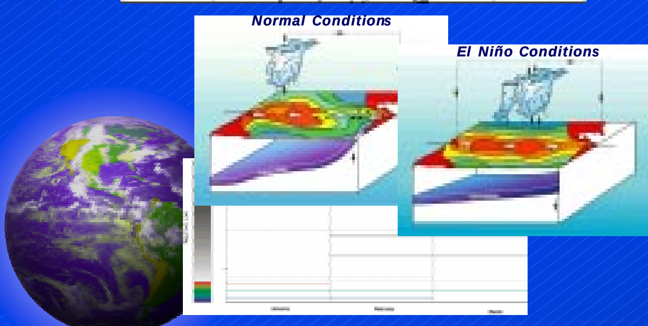
Multiple parameter, densely spaced data points for model input

High revisitation rates
Dozens to hundreds of satellites
Many different sensors (radar, passive, microwave, topography, winds, vegetation, static fields, etc)



Highly Detailed, Highly Coupled Models

Greater science understanding
Advanced computing
Advanced modeling



Rapidly changing macrophenomena

Configurable sensors
Adaptable interactive sensorweb
Autonomous operations

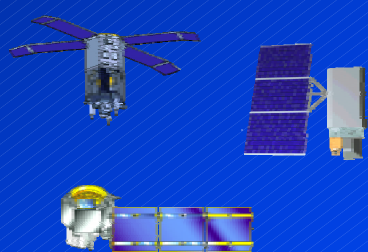
What Does This Mean in the Context of an ENSO-like Event?

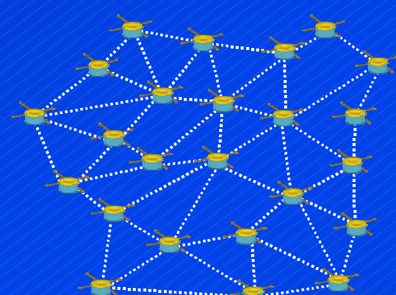
Very Large Number of Observations → Return useful data only → *Flexible, interactive, end-to-end information system*

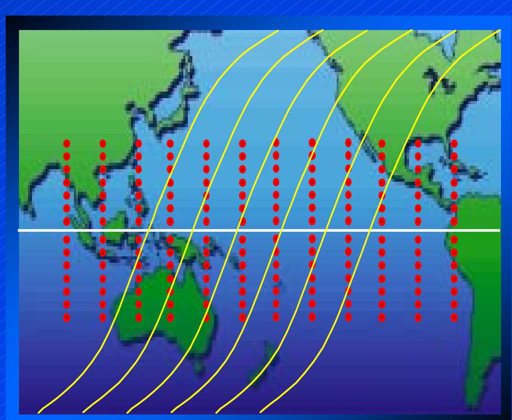
Useful Observations Change With Time → Reconfigurable, adaptable, learning system → *Intelligent agents*
Immersive environments
Human/machine integration

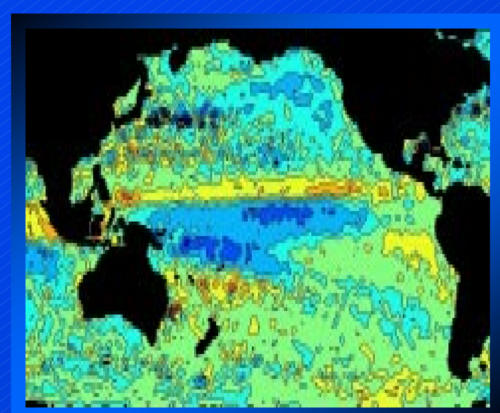
Managing End-to-End Information Flow

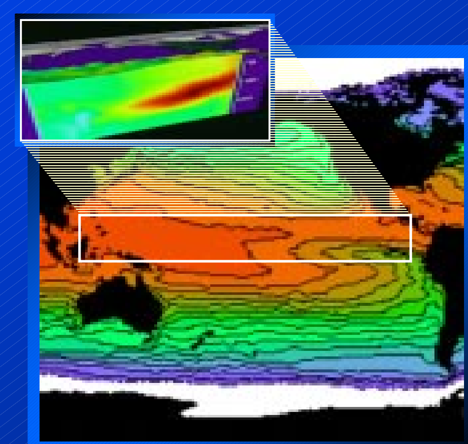
Observational Parameters	Information Parameters	Impact Parameters	Knowledge
Petabytes	Autonomous, In-space Calibration and Data Reduction	Interaction Between Modeling/Forecasting and Observation Systems	Human Machine Interactive Dissemination
Multi-platform, multi-parameter, high spatial and temporal resolution, remote & in-situ sensing	**Terabytes**	**Gigabytes**	**Megabytes**
Adaptable Sensors	Intelligent Sensor Web	Data Fusion	

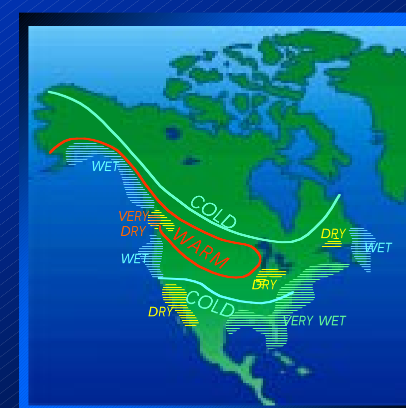












Science Enabling Understanding and Application

Observational Parameters

Multi-platform, multi-parameter, high spatial and temporal resolution, remote & in-situ sensing

Adaptable Sensors

Information Parameters

Autonomous, In-space Calibration and Data Reduction

Intelligent Sensor Web

Impact Parameters

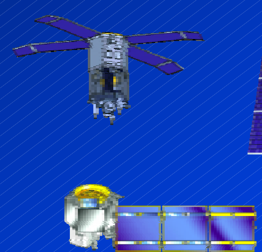
Interaction Between Modeling/Forecasting and Observation Systems

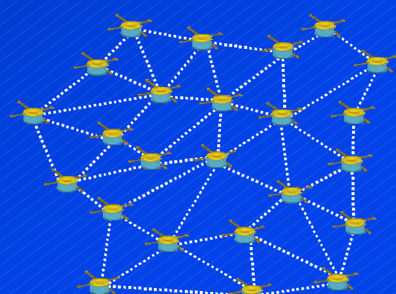
Data Mining & Fusion

Knowledge

Human Machine Interactive Dissemination

Nowcasting





Long term and Climate Archive

Initial and Boundary Conditions

Model Validation

Update Needs

Historical Record

Modeling

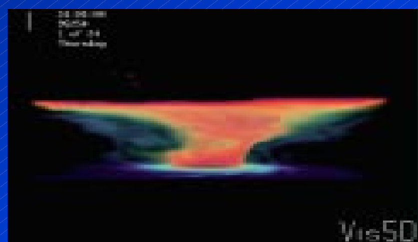
Science Understanding - Why & When

Predictive models

What Does This Mean in the Context of an Severe Weather Event?

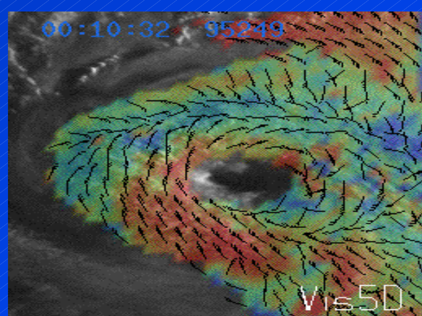
Sentinel systems for real-time detection

L1, L2, GEO, Molniya, non-Keplerian systems
High resolution (better than 100 m)



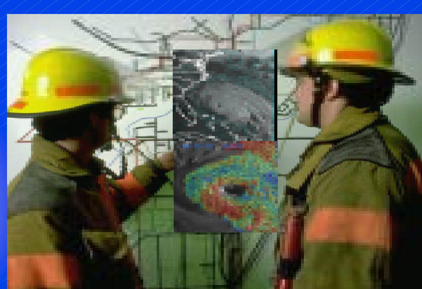
Real-time, autonomous sensor and forecasting system adaptation

Real-time, autonomous adaptive meshing and sensing
Taskable, in-situ and remote sensors



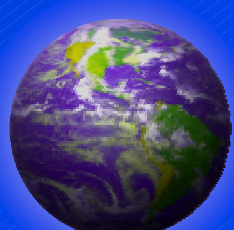
Real-time data fusion

Real-time data collection and combination from many sources

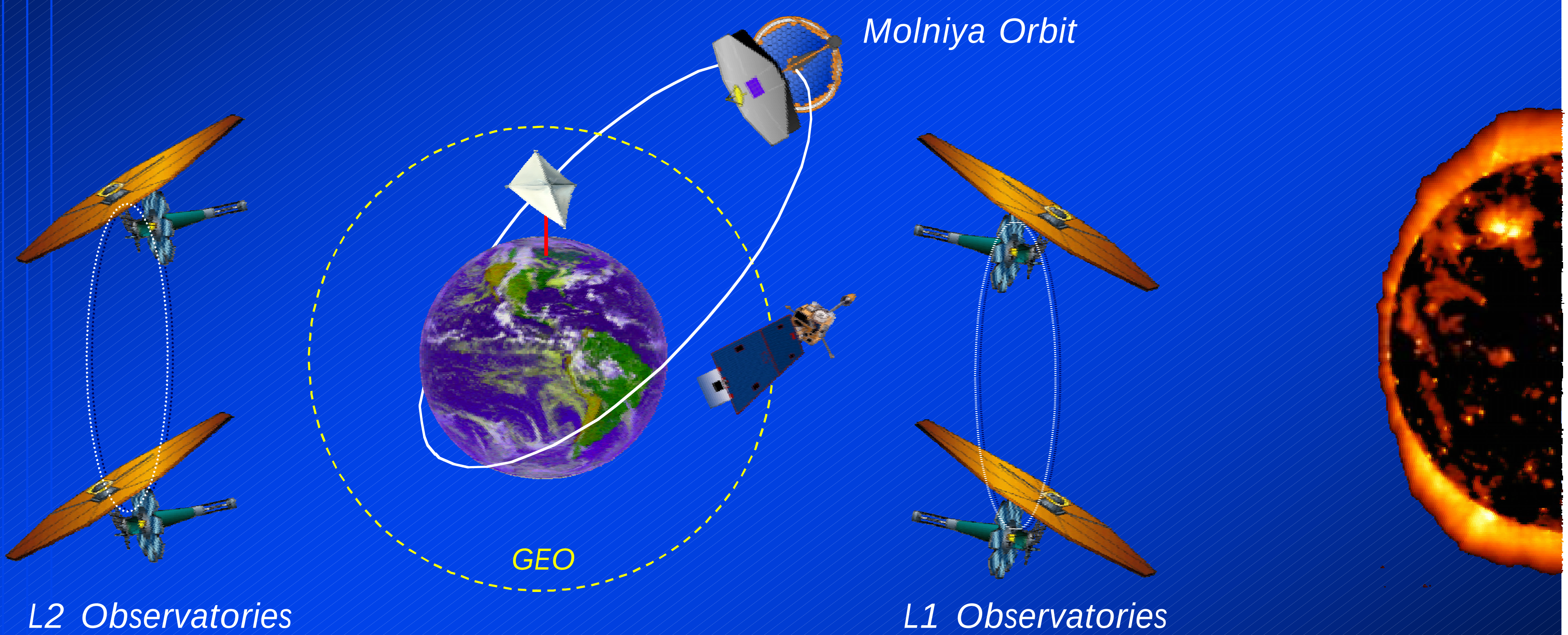


Real-time warning and data dissemination

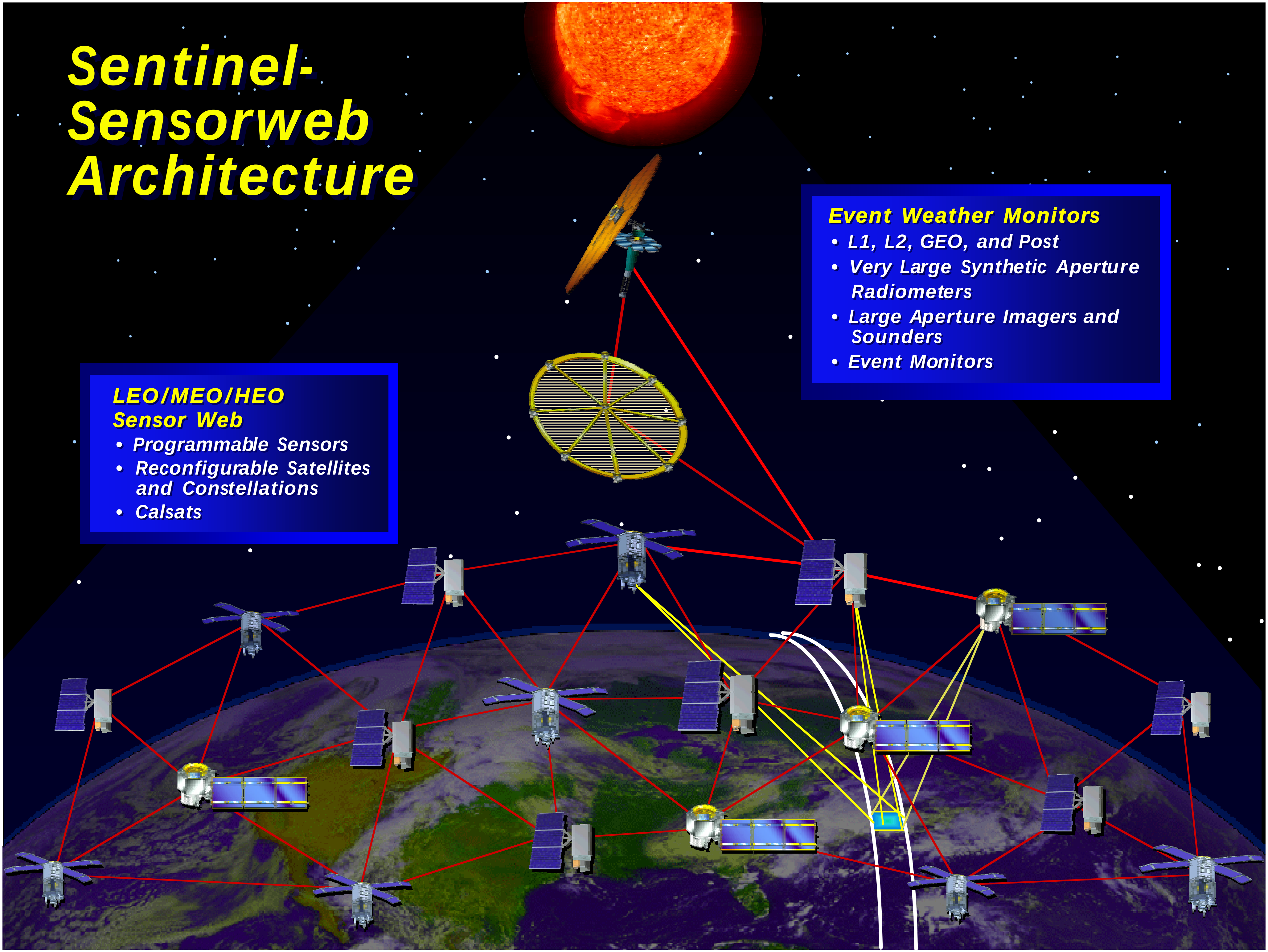
Wristwatch weather, personalized, geo-located forecasts
Real-time Internet



New Vantage Points



Work in Progress

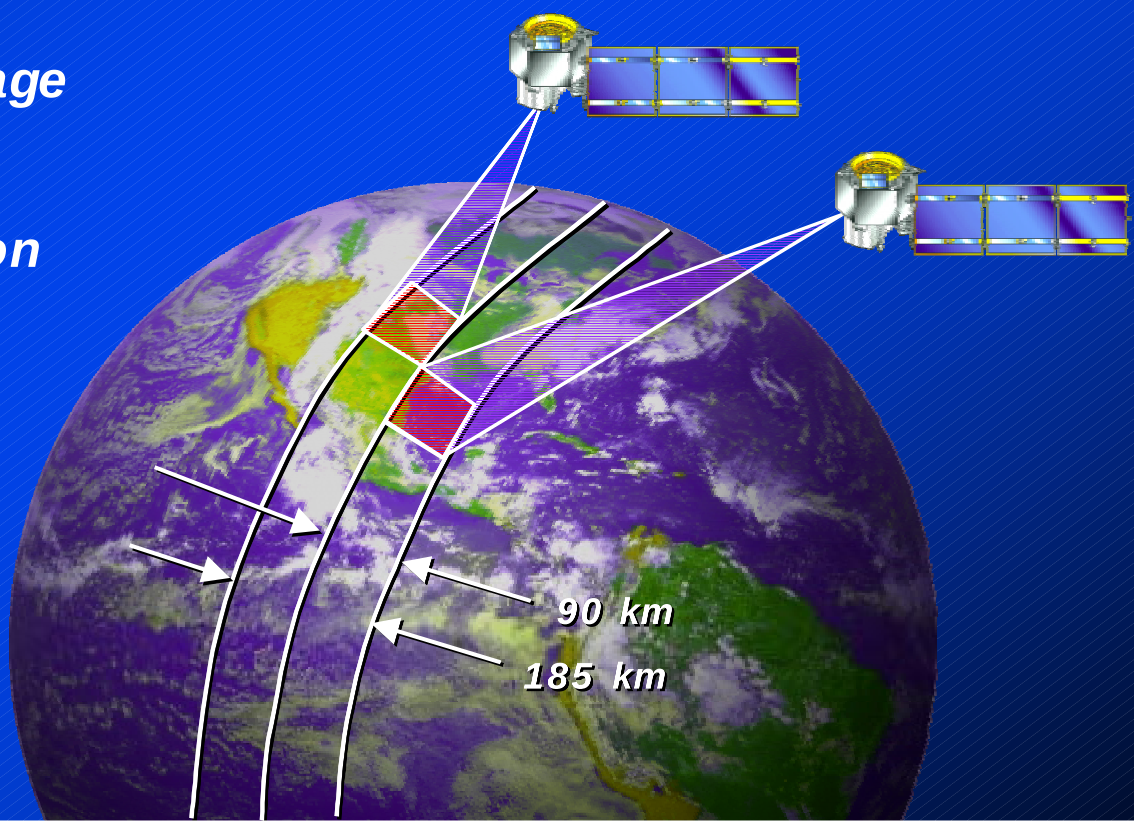

Sentinel-
Sensorweb
Architecture
Event Weather Monitors
• L1, L2, GEO, and Post
• Very Large Synthetic Aperture Radiometers
• Large Aperture Imagers and Sounders
• Event Monitors
LEO/MEO/HEO
Sensor Web
• Programmable Sensors
• Reconfigurable Satellites and Constellations
• Calsats

Vantage Point Trades
The Need to Mix and Match

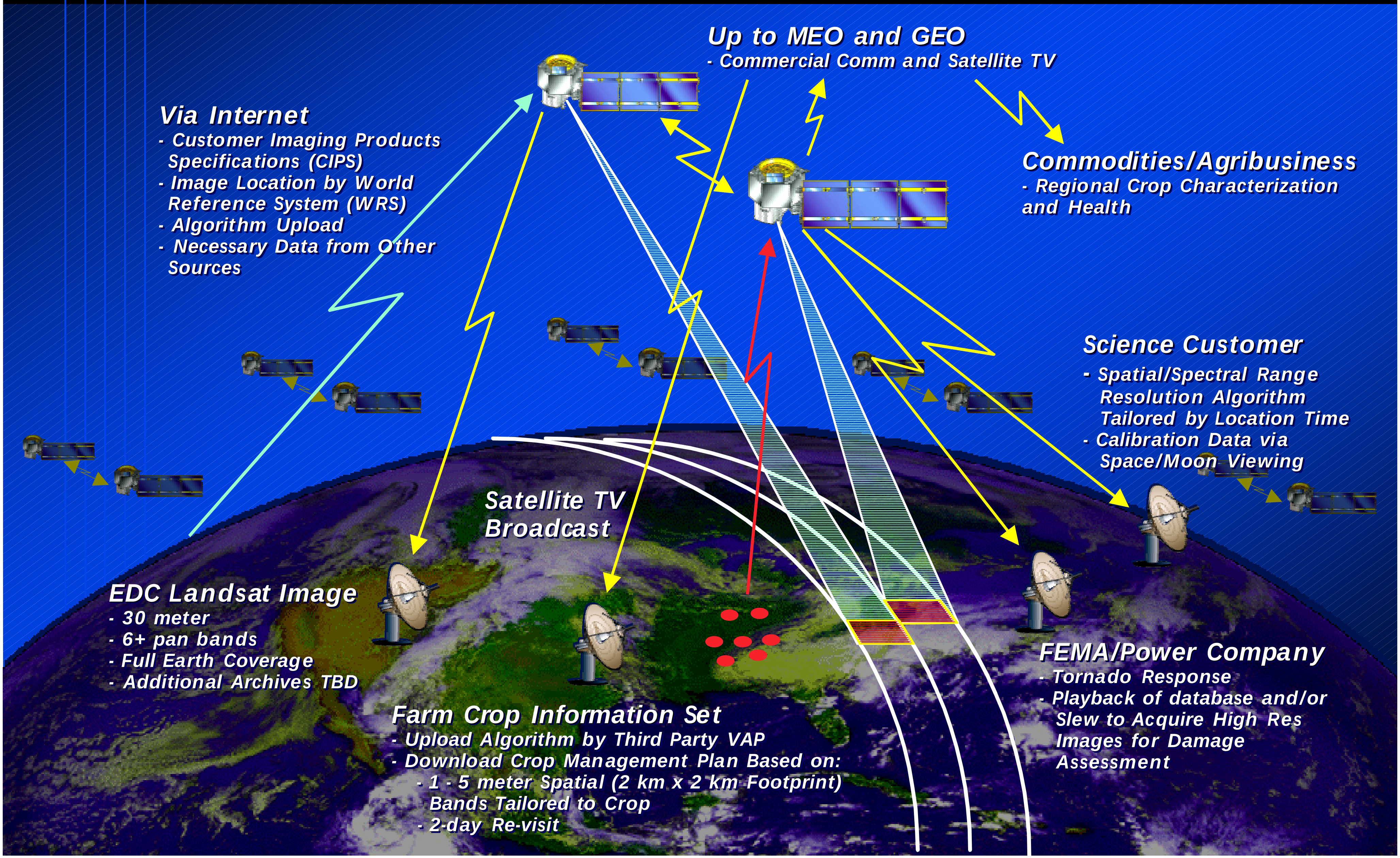
Attribute	In-Situ/ UAV/ Sub-Orb	LEO	MEO	GEO	Molniya	L1, L2
Synoptic View			X	X	X	X
Polar Viewing		X	X		X	X
Terminator Viewing		X	X	X	X	X
Active Sensors	X	X	?		?	
Continuous Ground Point View	X			X		
Equatorial Coverage	X	X	X	X	?	X
Limb Viewing	X	X	X	?	?	
Occultation	X	X	X			
Rapid Update/Full Earth Continuous Coverage			?	X	X	X
Number of Platforms	10^{4-7}	100's	6-10's	3-5+	2-12+	2-6
Aper. Size for 5m Visible Image		1 m	3-10	40 m	40 m	1600 m
Aper. Size for 1 km µwave		3 m	10-30	220 m	220 m	12000 m

Reconfigurable Land Surface Sensor System

- *Advanced Information Processing*
  - *Biological-based*
  - *16-day, Exabyte Recorder*
  - *Reference Ground Image for Autonomous Image Registration/ Navigation and Change Detection*
  - *On-the-Fly Information Processing Adaptation*
- *Three-Head Sensor*
  - *1 - 5 m Spatial*
  - *Visible to Thermal IR Full Hyperspectral*
  - *Formation Flying Constellation*
  - *16 Satellite Pairs to Provide Everyday Re-visit at the Equator*



Reconfigurable Sensors Autonomously Serve Many Users



A New Paradigm

Point monitoring and exploration

- Many, independent systems
  - Optimized for a single task
  - Design based on presumption of data of interest
  - Ex post facto combination of data

Holistic, integrated insight, foresight and discovery

- Single integrated system
  - Adaptable to many 'new' tasks
  - Flexible response
  - Replenishable and scalable
  - Evolving infrastructure

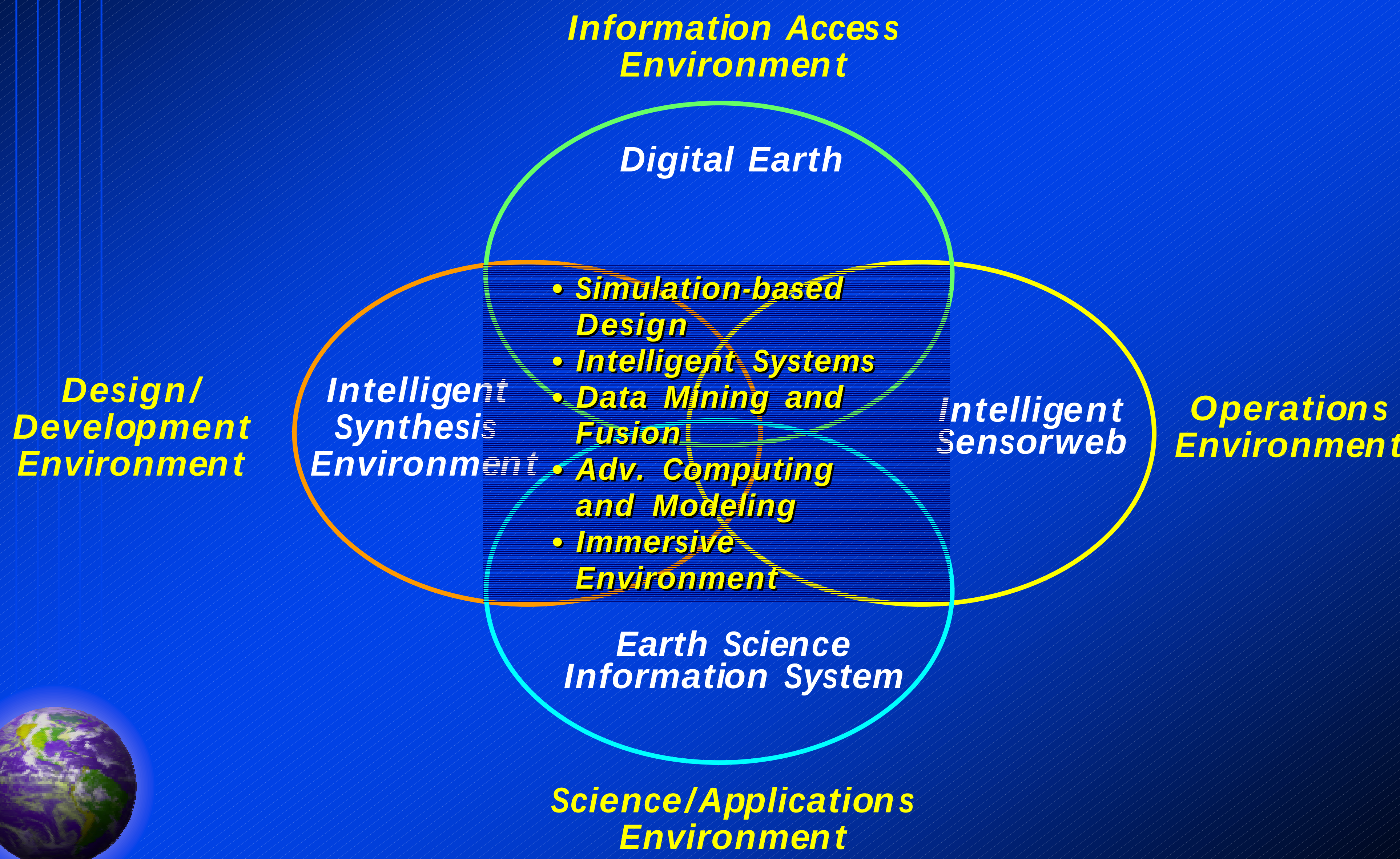
Science ⟷ Technology ⟷ Adaptive Infrastructure ⟷ Investigations/ Applications

In-depth Discussion Topics

Architectural features and detailed descriptions

Critical technologies and roadmaps

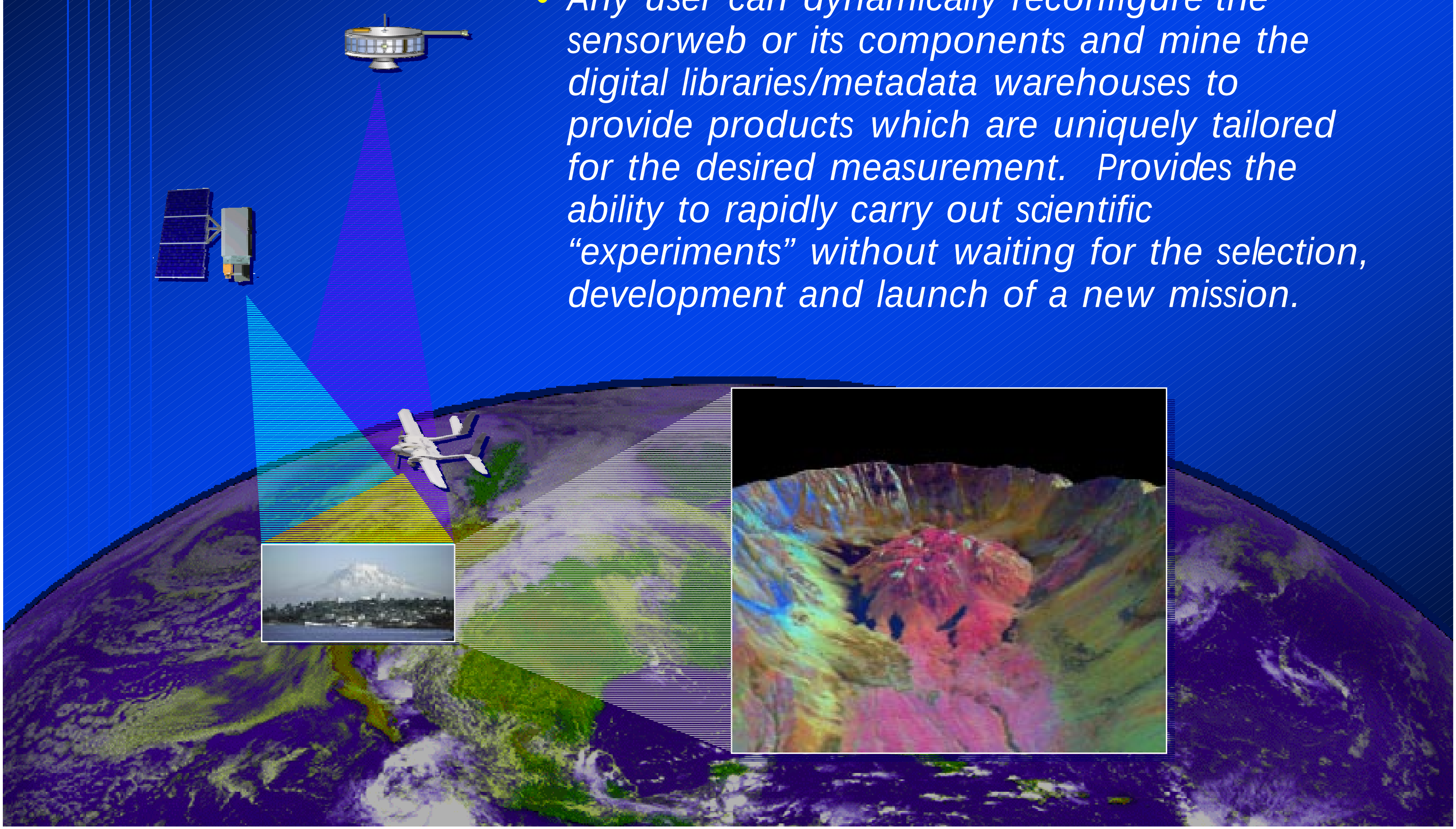
Information Technology Thrusts



Architecture and Facets

- On-Demand “Virtual Instruments”
- Real-Time Adaptive Remote and In-Situ Sensor Swarms
- Interoperating Sensor Web
- Distributed Information-System-in-the-Sky
- Earth Science Information Web

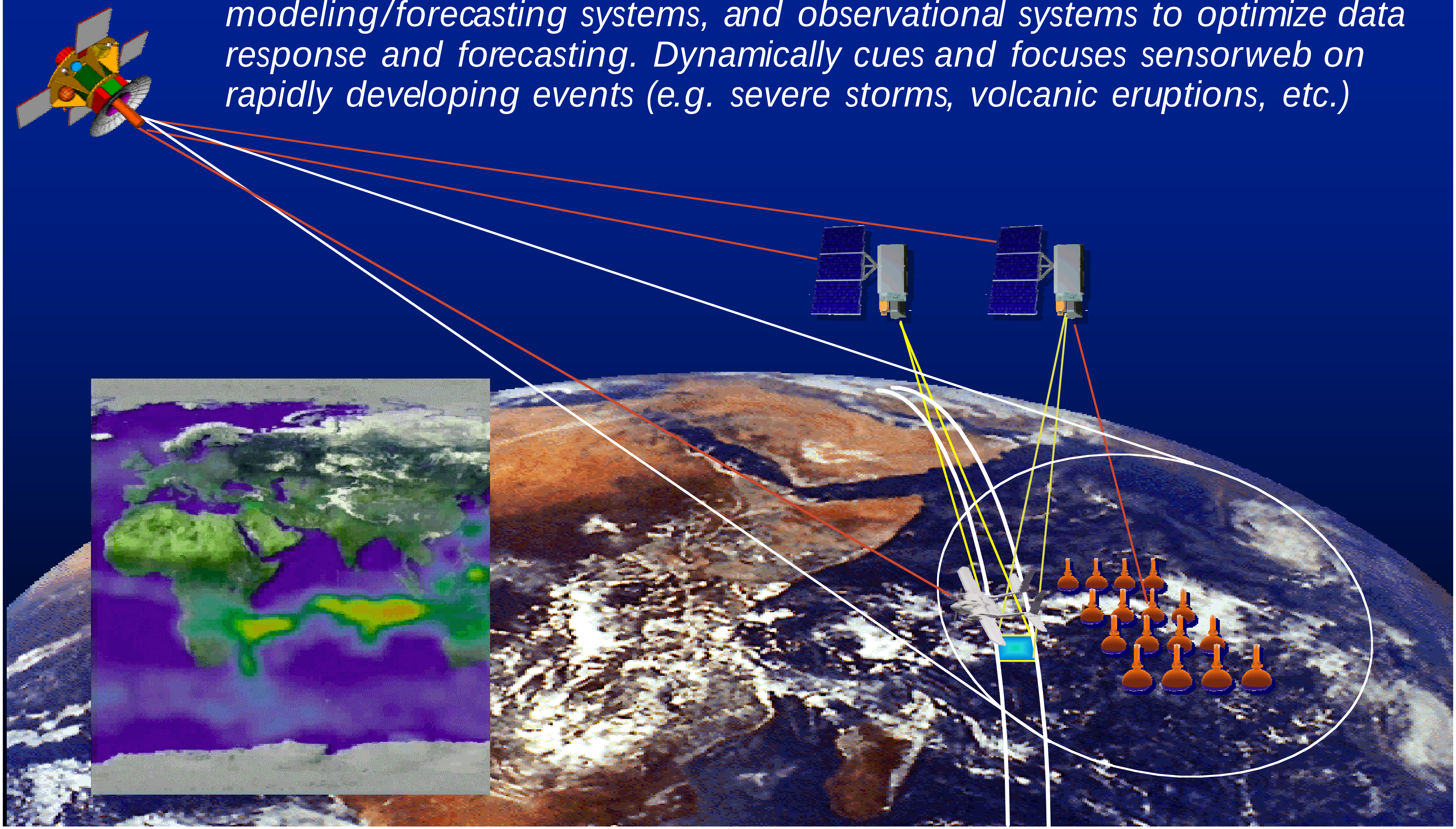
On-Demand "Virtual Instruments"



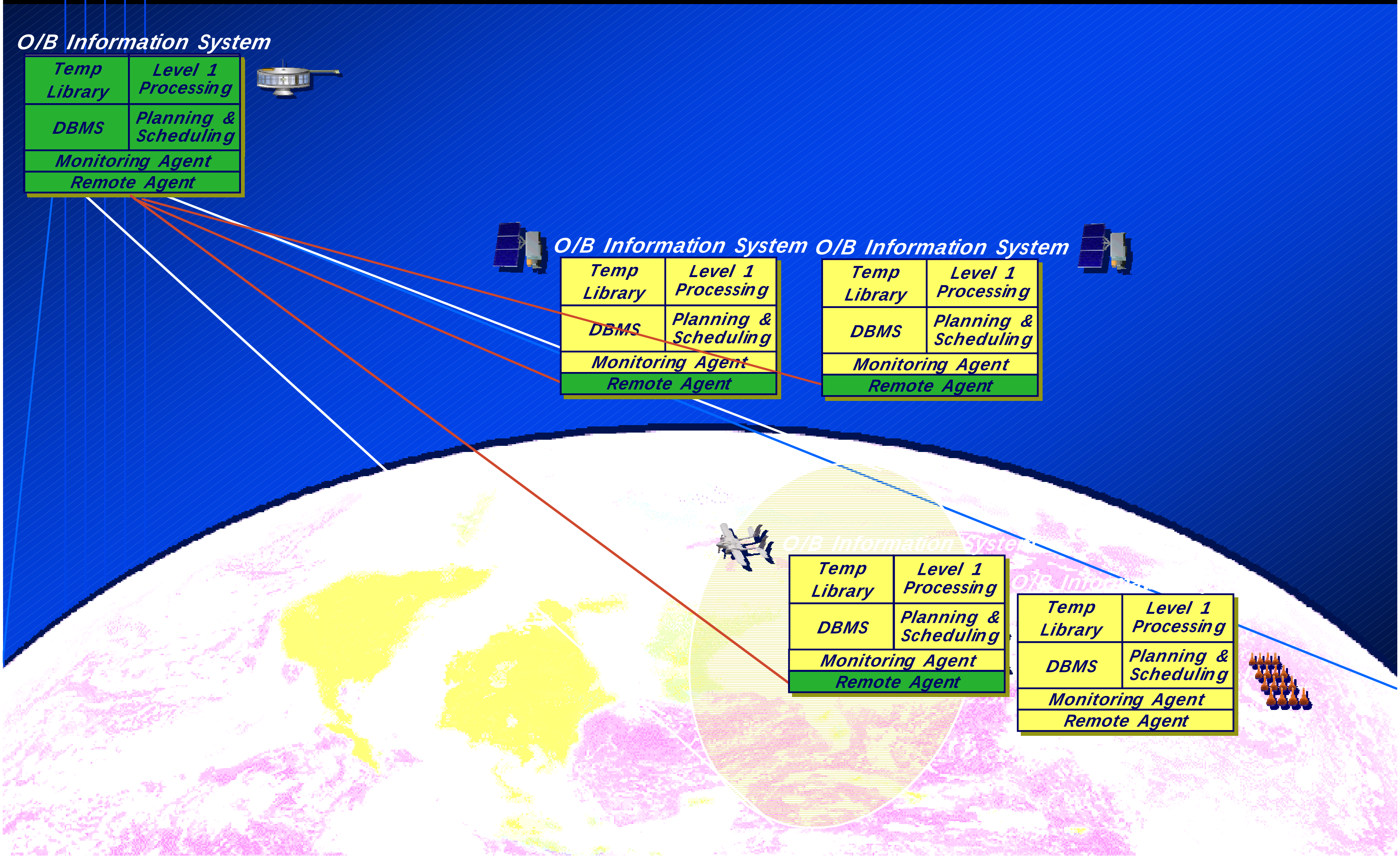
- *Any user can dynamically reconfigure the sensorweb or its components and mine the digital libraries/metadata warehouses to provide products which are uniquely tailored for the desired measurement. Provides the ability to rapidly carry out scientific "experiments" without waiting for the selection, development and launch of a new mission.*

Real-Time Adaptive Remote and In-Situ Sensor Swarms

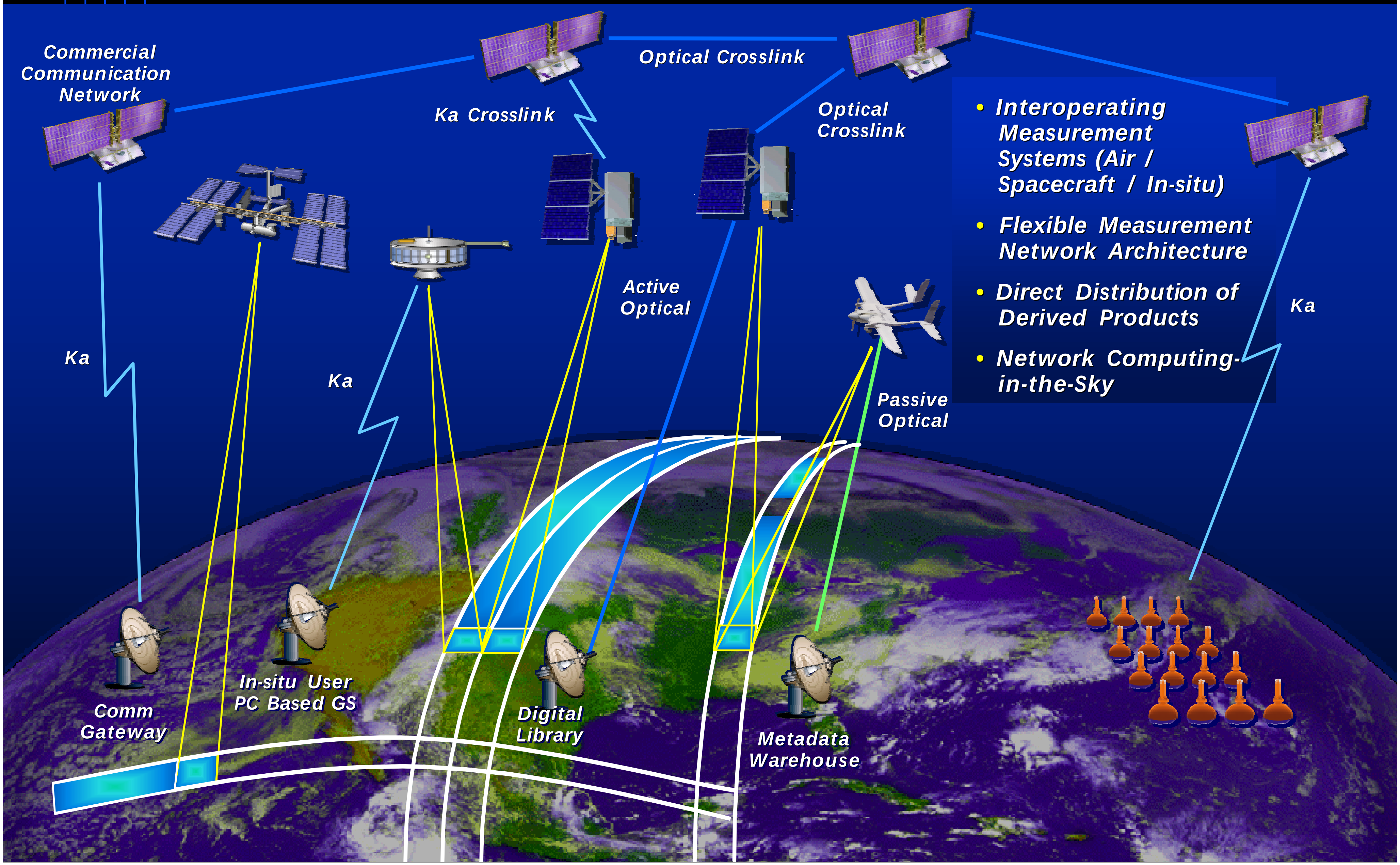
- Allows real-time self-direction, interaction, and adaptation of humans, modeling/forecasting systems, and observational systems to optimize data response and forecasting. Dynamically cues and focuses sensorweb on rapidly developing events (e.g. severe storms, volcanic eruptions, etc.)



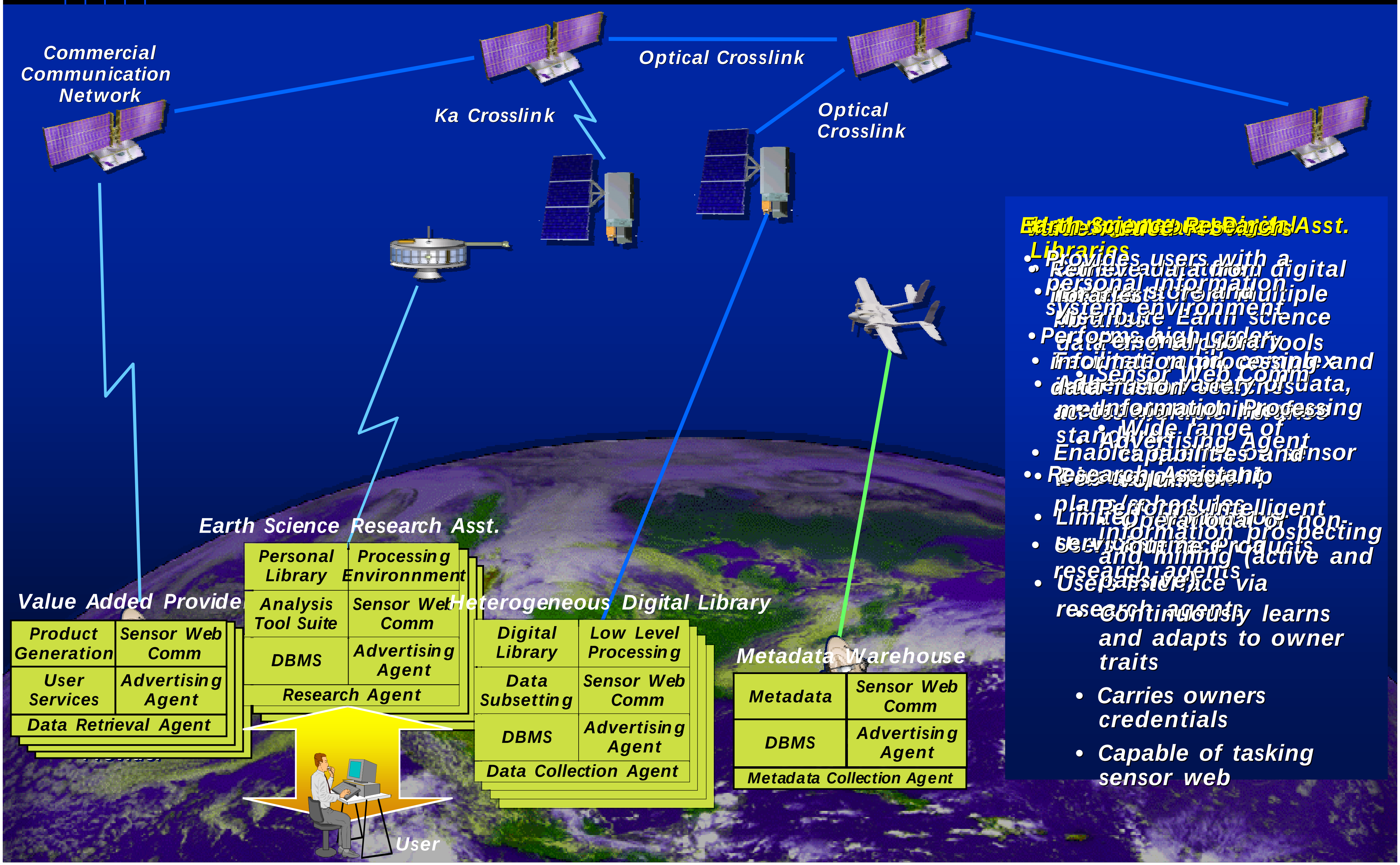
Interoperating Sensor Web



Distributed Information-System-in-the-Sky



Earth Science Information Web



Critical Technology Areas and Roadmaps

- *Reconfigurable Sensing*
- *Large Ultra-lightweight Deployable Structures*
- *Large Aperture Systems*
- *Large Deployable Systems: Ultra-high Resolution Imaging*
- *Rapid and Low-Cost Sensor Production*
- *New Vantage Points*
- *Miniaturized Observatories and Intelligent Web*
- *Onboard Processing*
- *Intelligent Agents*
- *Neural Processing*
- *Distributed Information-System-in-the-Sky*
- *Integrated Life Cycle Simulation*
- *Advanced Engineering Environment Enables the Rapid Production of New Capabilities*

Reconfigurable Sensing

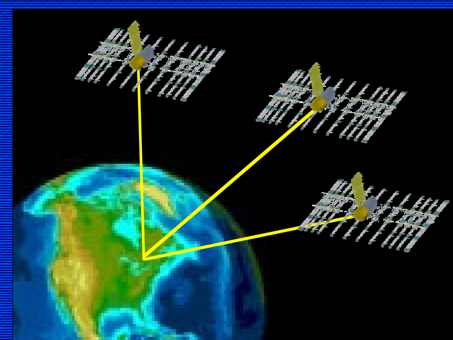
Resolution

50 m vert
10 km horz

100 m vert
20 km horz

250 m vert
50 km horz

Partial Globe/ small formations/ mixed sensors
- LIDAR
- Radio occultation
- Hyperspectral



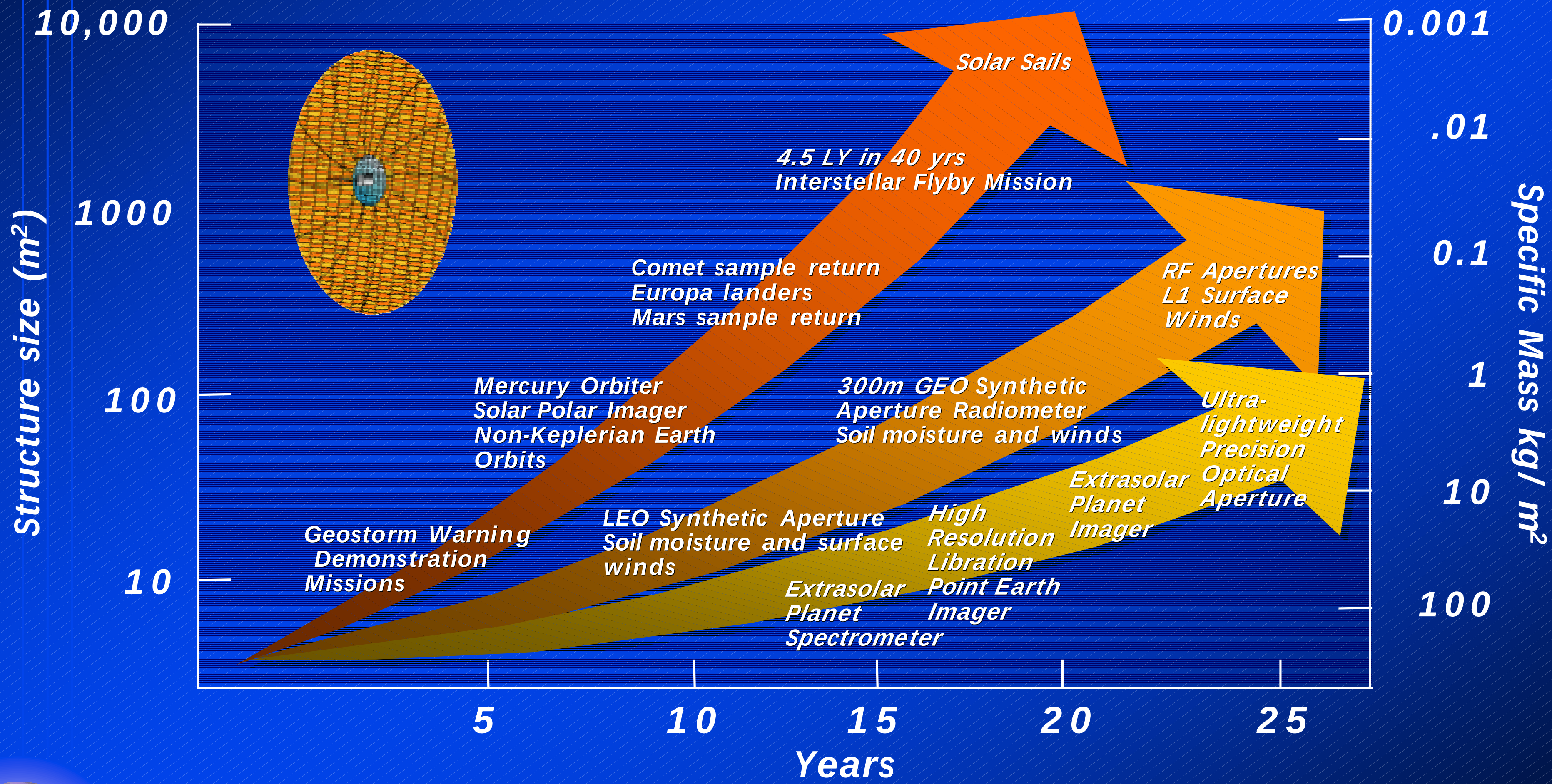
Most of Globe/ large constellations
- Microwave Synthetic Aperture
- Programmable filter, active sensor
- Active dynamic range lidar

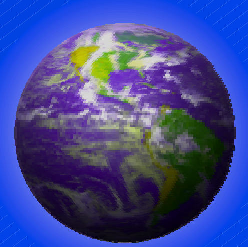
Entire Globe
- Fleets of low cost miniature instruments
- Webs of synthetic aperture
- Full suite and coverage sensor network

5 10 15 20 25

Years

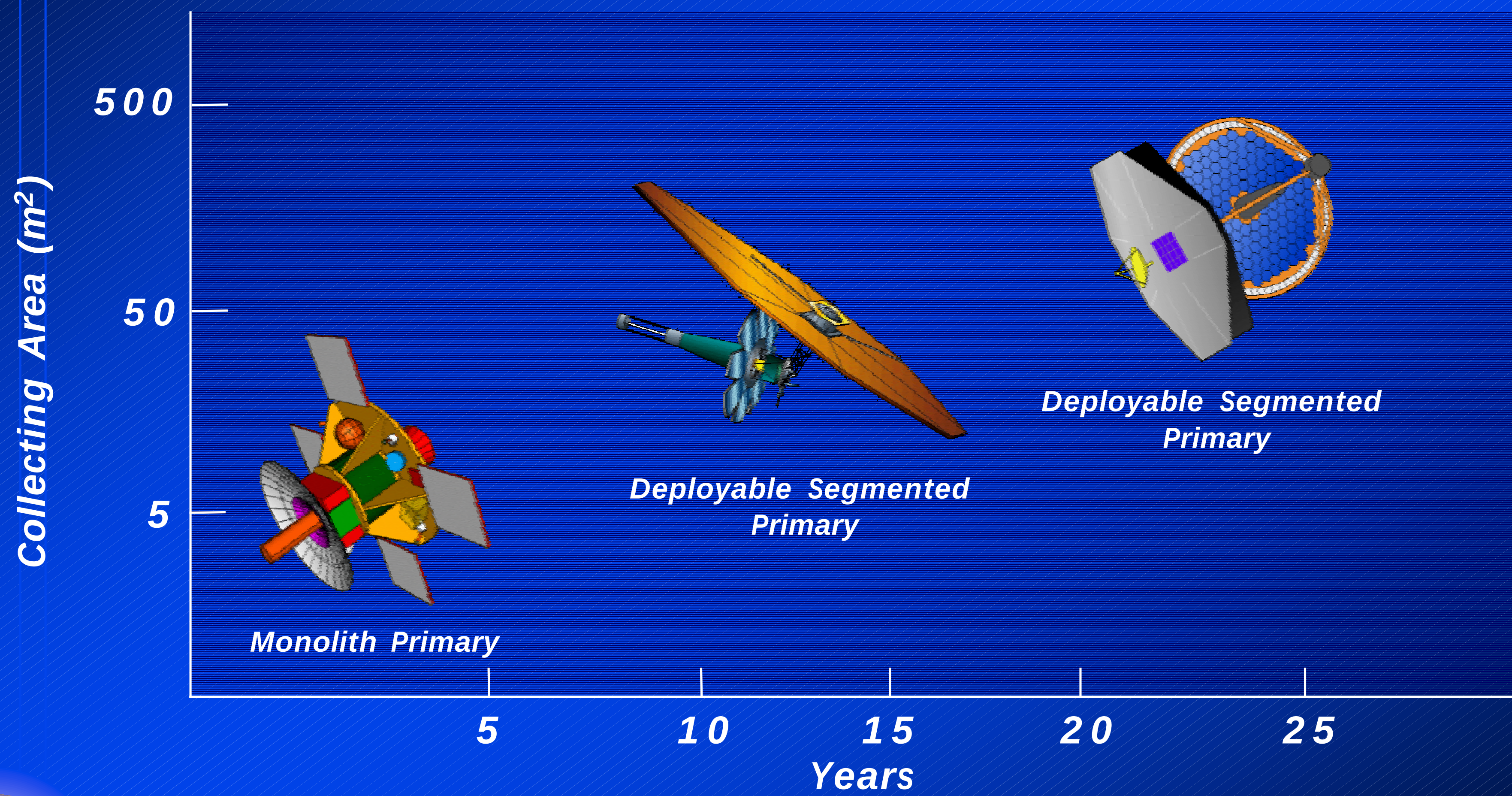
Large Ultra-lightweight Deployable Structures





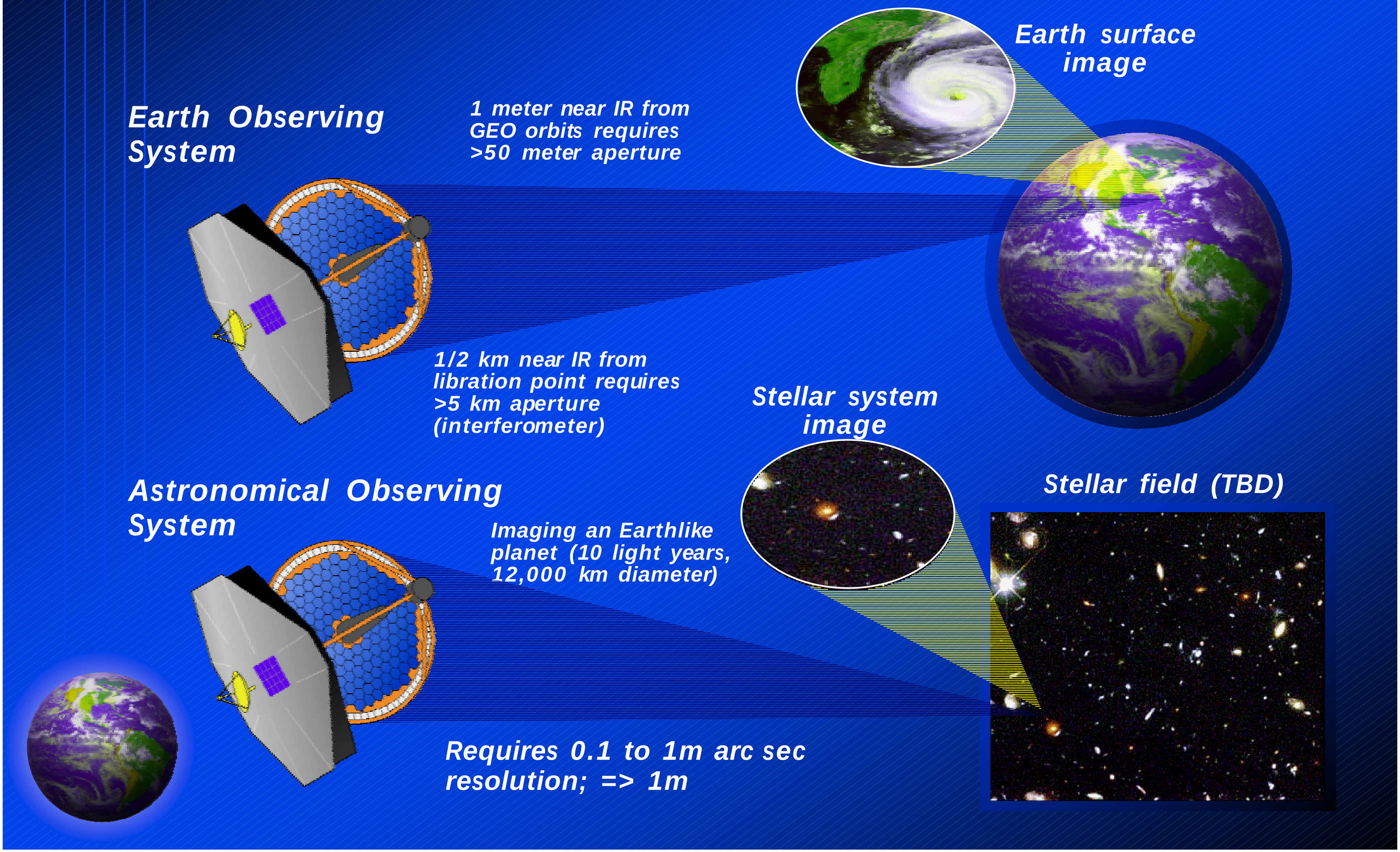
Radical advances in ultra-large, ultra-lightweight deployable structures causes paradigm shifts to enable frontier science

Large Aperture Systems



Increased collecting area by two orders of magnitude

Large Deployable Systems: Ultra-high Resolution Imaging



Rapid and Low-Cost Sensor Production

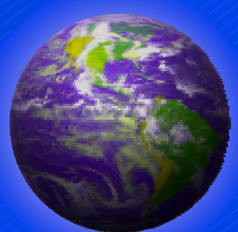
- *An Advanced Engineering Environment enables integrated imagination, simulation, design, development, and testing allowing the creation and deployment of new sensors in days or weeks. MEMS techniques and economies of scale enable the inexpensive production of a vast number of in-situ and remote sensors.*

New Vantage Points

- *Hundreds of satellites in constellations and formations view the Earth-Sun system from LEO to the L1 Triana perspective. Millions of in-situ sensors reside on the Earth's surface, in its interior, the oceans, the cryosphere, the atmosphere, and in the magnetosphere.*

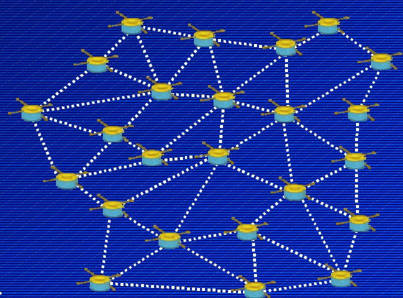
Principal Investors:
- ***NASA***
- ***DoD***
- ***Commercial Aerospace***
- ***Universities***
- ***Foreign Agencies***

Beneficiaries:
- ***Local and National Governmental Agencies***
- ***Commerce***
- ***International Organizations***
- ***Universities***



Advanced Capabilities	***5 Years***	***10 Years***	***25 Years***
• *Miniaturized Observatories* • *Robust, Compact Instrument Architectures* • *Miniaturized/Programmable Components* • *Aperture Synthesis* • *Deployable Apertures* • *Low Cost Production*	*Small Observatory* • *Separate S/C and Instrument* *~100Kg* *<M$ each* • *Few S/C per mission* • *3-5 year life*	*Nano-Observatory* • *Multifunction subsystems* *~10Kg* *<500K$ each* • *10's to 100's* • *5-8 year life* • *Advanced maneuverability*	*Pico-Observatory* • *Integrated sensorcraft* *~1Kg* *<100K$ each* • *Many 100's* *>10 year life* • *Unlimited maneuverability*
• *Advanced Mobility and Placement of Sensors* • *Airborne Mobility (UAVs, balloons, nano-rovers)* • *Land/Cryosphere Mobility (nano-rovers, burrowers/penetrators, "seeded" sensors)* • *Ocean Mobility (moored/drifting/ disposable buoys, surface/sub-surface nano-rovers)* • *Space Mobility (deployerships, space warehouses, formation flying, constellation maintenance)*	*Nano-Rovers* *~Kg* • *Walking, wheeled*	*Nano-Rovers* *<100's g* • *Walking, hopping, flying, burrowing, swimming*	*Nano-Rovers* *<10's g* • *Walking, hopping, flying, burrowing, swimming*

Miniaturized Observatories and Intelligent Web



Mass

5 kg

10 kg

100 kg

Femto Observatory
- 1000s per constellation
- Advanced autonomy and interoperability
- <$50K each

Pico Observatory
- Many 100s per constellation
- Autonomous
- Advanced maneuverability
- <$100K each

Nano Observatory
- 10s to 100s per constellation
- Limited autonomy and maneuverability
- <$500K each

Intelligent Sensor Web
- Event anticipation
- Distributed tasking of sensor web

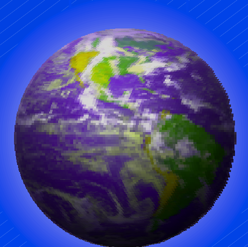
Autonomous Constellation Control
- Intelligent "discovery"
- Autonomous retasking of assets

Autonomous Formation Flying
- Coordination of multiple constellations
- Replenishment capability

5 10 15 20 25

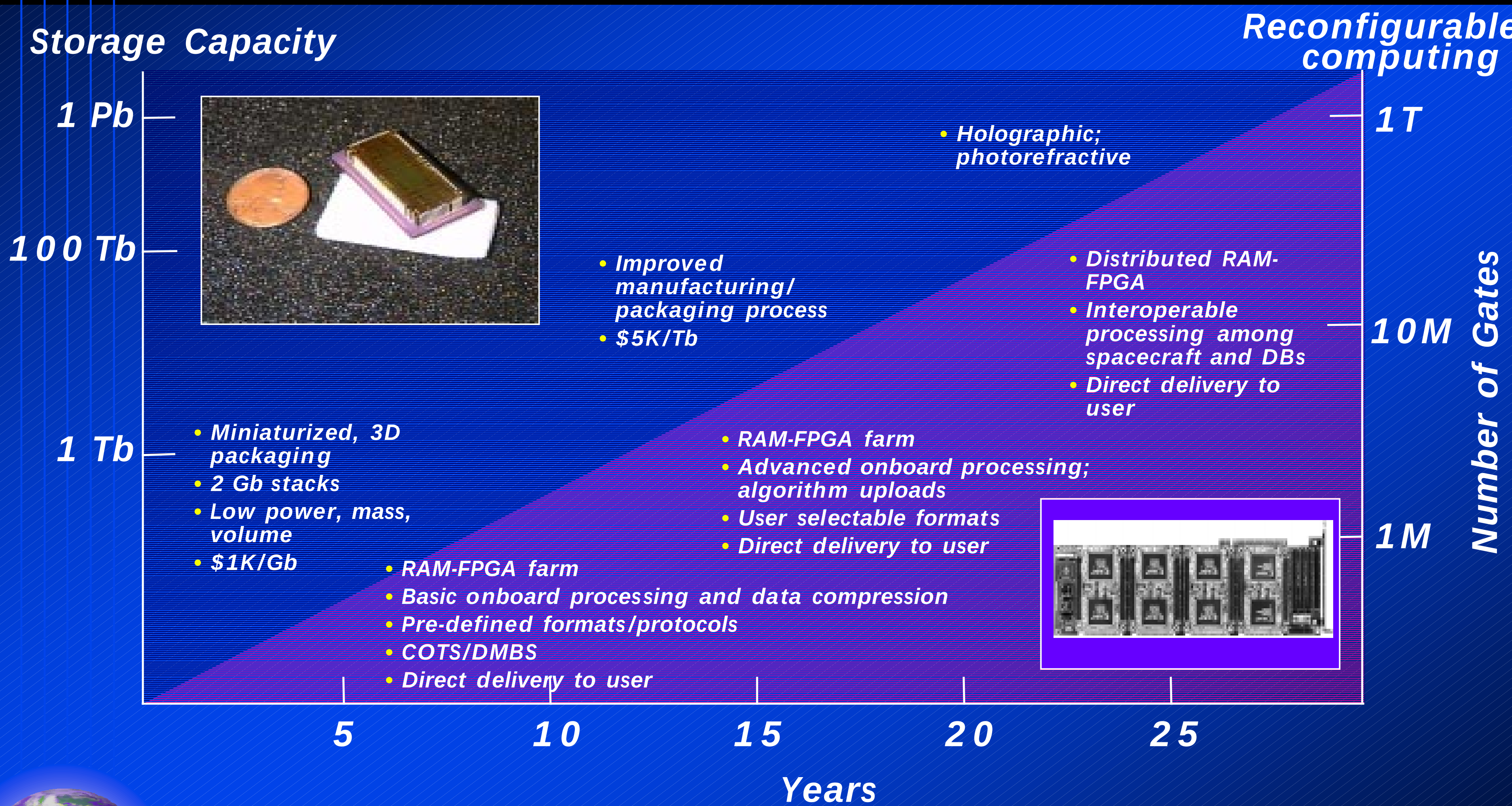
Years

Autonomy



Revolutionize the scientific investigations of Space Science and Earth Science enterprises by creating new generations of high performance integrated spacecraft/instrument which are dramatically lighter, compact, and less cost

Onboard Processing



Order of magnitude increase in storage capacity and number of field programmable gates, while reducing cost to provide onboard information processing and product delivery to user

Intelligent Agents

Capabilities

Onboard Monitoring Agents
- Automated cloud cover assessment
- Limited scheduling

Research Agents
- Active data mining
- Active data prospecting
- Multilingual

Onboard Monitoring Agents
- Event recognition
- Autonomous scheduling

Research Agents
- Active & passive data mining
- Active & passive data prospecting
- Self adapting/learning
- Carries users credentials

Onboard Agents
- Event anticipation
- Distributed tasking of sensor webs

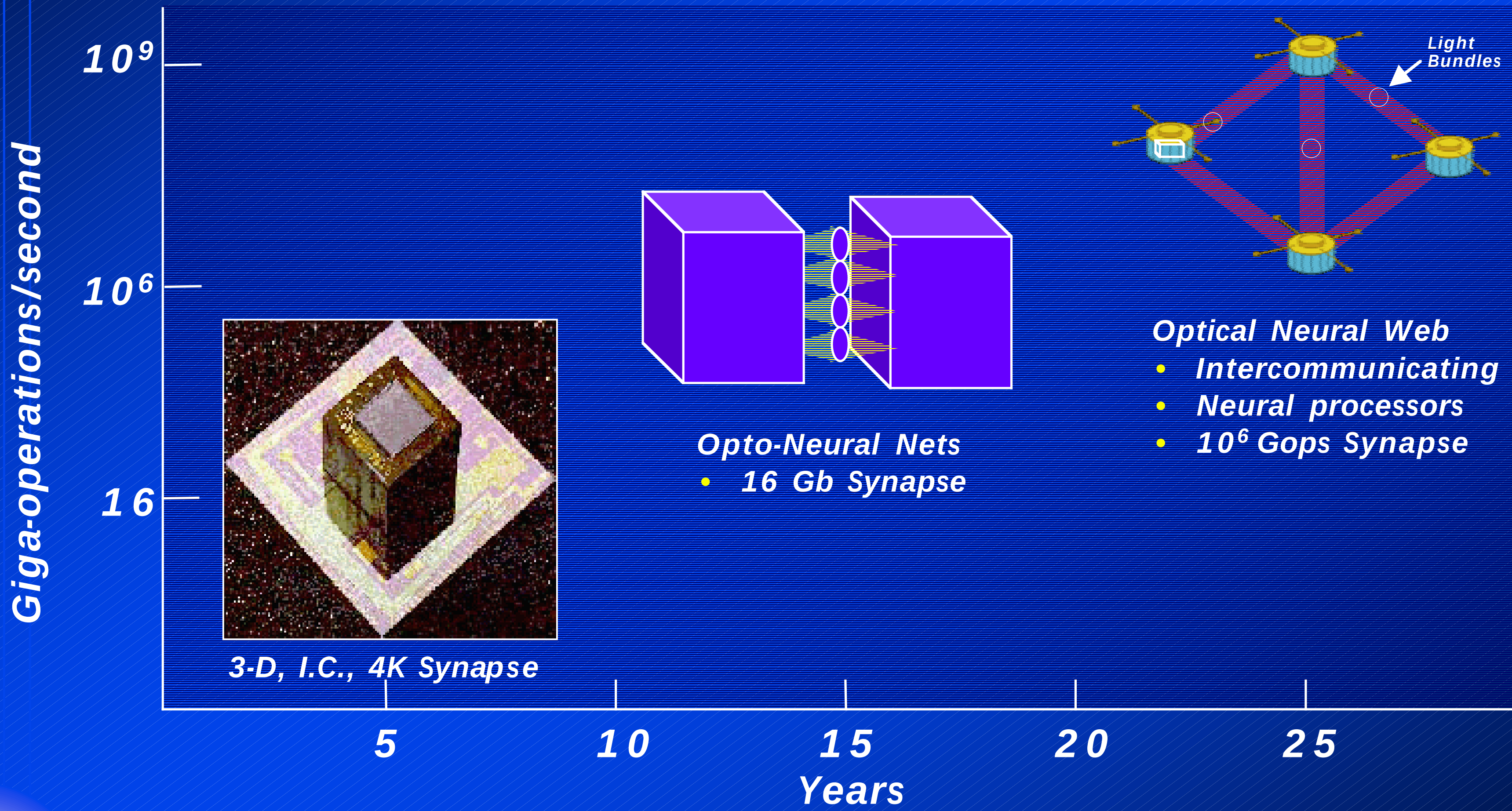
Research Agents
- Autonomous information mining and prospecting
- Intelligent tasking of sensors and information web

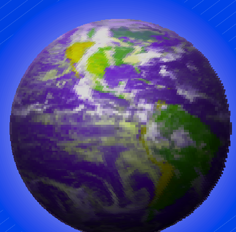
5 10 15 20 25

Years

Increasing intelligence and autonomy of agents to carry out operational activities

Neural Processing





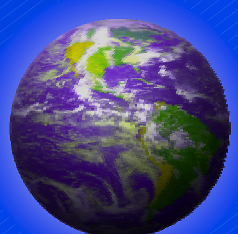
Synapse = Connection between 2 or more neural cells

Distributed Information-System-in-the-Sky

- *Advanced on-board information system directly accessible by users for data acquisition, processing, and product retrieval*

Principle Investors:
- ***NASA***
- ***DOD***
- ***Commercial Aerospace***
- ***Universities***
- ***Foreign Agencies***

Beneficiaries:
- ***Local and National Governmental Agencies***
- ***Commerce***
- ***International Organizations***
- ***Educational Groups***



Advanced Capabilities	***5 Years***	***10 Years***	***25 Years***
• ***Advanced Communications***	*High rate Ka/X band*		
	PC-based ground station		
	Laser/Optical (active)		*(passive)*
	LEO commercial (low rate)	*(high)*	
		GEO commercial (high)	
		Libration Point	
• ***Autonomy***	*Autonomous GN&C*		
	Fault detection, isolation ,and recovery		
		Multi-sensor synchronization	
		Closed loop, self-adjusting S/C, observations optimization	
	Beacon operations		*Smart instruments*
	Transparent S/C operations	*Autonomous Formation Flying*	
• ***On-board Information System***	*High volume SSR*		
	SAFE, Protocol X, Space-based IP and ATM based protocols		
	Reconfigurable processing (HW and GW)		
	Direct product delivery to users		
	On-board processing		*Network Computing*

Integrated Life Cycle Simulation

Capabilities

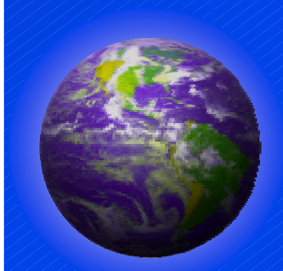
- Program formulation (1-12 months)
- Design verification via ETE simulation
- Intelligent access to tools and resources
- Modeling and analysis tool suite
- Operations simulation

- Program formulation (1 month)
- Mission cost reduction by 10x and frequency increase by 5x
- Virtual/physical hybrid ETE simulation
- Program cost reserve reduction by 2x
- Access to highly dynamic/interactive expert systems
- Full verification by simulation
- Auto-code generation from simulation

- New capability development less than 1 year
- Fully immersive development and simulation environment
- Real-time simulation and science data generation
- Acquisition in days
- Fully immersive operations and science data

5 10 15 20 25

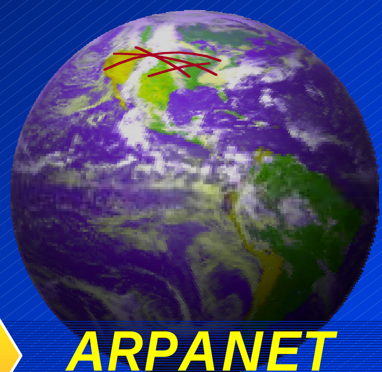
Years



Advanced engineering environment provides increases in productivity and product quality while reducing the concept-to-launch time

Information Revolution

Tens of Connections



IP
WAN

ARPANET

Hundreds of Connections

TCP
FTP

Internet

Millions of Connections

HTML
Mosaic

WWW

- Large Aperture Systems
- Formation Flying
- Data Fusion

- Sentinels
- Small Clusters
- Virtual Inst.

- Adaptive Sensors
- On-Board Processing
- Intelligent Systems
- Neural Processing
- Intelligent Agents
- Immersive Environments
- Information System-in-the-Sky

- Digital Earth
- Solar System Wide Web
- Seamless Human/ Machine Interaction
- Intelligent Sensor Web